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EXPERIMENTAL FIELD STUDIES ON SHADE TREE FERTILIZATION

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MUCH OF THE PUBLISHED INFORMATION concerning response of trees to the addition of nutrient elements comes from the fields of pomology and forestry, very little from arboriculture. In orchards, the response is usually measured in yields of fruit, which may or may not be related to tree growth. The fertilization studies in forestry have been directed toward improving the growth of seedlings in the nursery or of young trees in plantations. The responses may be quite different from those of established trees in lawn areas. Recent reviews of field studies on nutrient response in forest trees were prepared by Stoeckeler & Arneman (1960) and the Duke University School of Forestry (Anon. 1959). Foliar application and foliar absorption of nutrients is a relatively new field; this research was reviewed by Boynton (1954) and by Wittwer & Teubner (1959).

The fertilization studies in pomology and forestry have little direct application for the arborist and the homeowner, who are interested in maintaining aesthetic appeal of shade trees by improving the color, promoting more vigorous growth, or restoring the condition of trees that have been weakened by disease, insect attack, or unfavorable environmental conditions.

Early research on fertilization of shade trees was conducted for 2 years on American elm and Norway maple by Jacobs (1929) in Kent, Ohio. Jacobs applied a 5.75-8-3 fertilizer to established street trees approximately 2 inches in diameter. His results indicated little difference in benefits between fall and spring treatments but a decided benefit from either treatment.

Beilman (1934) reported studies on shade tree feeding at the Missouri Botanical Garden in St. Louis. His recommendations are based on observations of response to applications of various fertilizer treatments over several years rather than on controlled, replicated experiments. He concluded that the fertilizer formulation 10-8-6 is best for shade trees, which "cannot be over-fed; they require large amounts of food."

Wyman (1936) reported a study on nursery-size pin oaks transplanted into a field maintained under lawn conditions. He compared ammo-phos (15-30-0 and 11-46-0) and ammonium sulfate by placing the fertilizers in holes 10 inches deep and 12 inches from the tree trunks on both stony clay and silty clay loam soils. Three years of data show that both fertilizers materially increased tree growth. The ammo-phos produced a greater response than ammonium sulfate on both soil types; in 2 of the 3 years, the response was greater on the silty clay loam soil than on the other type.

Chadwick (1935, 1937, 1940) contributed considerable information on shade tree fertilization practices through his study of a block of 500 American elms, *Ulmus americana* L. He recorded 7 years of data (1933–1939) on the results from 12-6-4, 6-6-4, ammonium sulfate, and a mixture of ammonium sulfate and superphosphate (or an approximate equivalent) applied in the spring, summer, and fall to the soil surface over the entire area beneath the spread of the branches. Chadwick's study indicated that fall was as favorable as, or more favorable than, other seasons for application of fertilizers and that complete fertilizers were more beneficial than nitrogen alone.

Chadwick et al. (1950) in a test on Norway maples, *Acer platanoides* L., evaluated various methods of fertilizing shade trees. The trees, averaging 1.5 inches dbh at the start of the experiment, had been planted in the test plot in the fall of 1935. They were fertilized in 1941 and again in 1947. Trunk diameters were recorded annually, the last time in 1948. The greatest increase in diameter resulted from surface application of a complete fertilizer to a mulch, 2 to 3 inches deep, of rotted stable manure around each tree. The complete fertilizer alone (without peat or stable manure) produced better results when applied to the surface than when placed in holes made by a drill or crowbar. There were no significant differences between the other methods of application: fertilizer applied with air or water, or both air and water, in drilled holes, or fertilizer placed in holes made with a crowbar. In plots from which one or more of the nutrient elements had been omitted, nitrogen was considered the limiting element; when phosphorus was added to nitrogen, a greater stimulation resulted than from nitrogen alone.

Pirone (1951) reported experiments in New York City with foliar application of nutrients to more than 300 street trees of five species. He noted that the general appearance of treated trees was better than that of untreated trees. His chemical analyses of leaves from a small number of London plane trees and pin oaks showed more of both nitrogen and phosphorus in leaves from the treated trees than in leaves from the untreated trees. He concluded that both nitrogen and phosphorus can be absorbed directly by leaves and are of benefit when applied as foliar sprays.

The investigation reported here was initiated to compare and evaluate current shade tree fertilization recommendations concerning formulations and methods of application. It is expected to form the basis for future shade tree research relating soil fertility and tree vigor to certain physiological and pathological diseases.

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EXPERIMENTAL PROCEDURES IN TREE FERTILIZATION

The experimental area (Fig. 1) used in our tests of shade tree fertilization was located on the grounds of the Morton Arboretum near Lisle, Illinois. This area is approximately 25 miles west of Chicago. It has a 2% to 4% slope to the south and 7 to 14 inches of topsoil. The soil is classified as Andres silt loam (293).

An Illinois soil survey report (Wascher et al. 1962) characterized this soil as follows: "Andres is high in organic matter, medium to slightly acid, low in available phosphorus, and about medium in available potassium. Water-holding capacity is high but moisture movement within the silty clay loam till is somewhat slow."

In a representative profile of Andres silt loam, the surface soil is black to very dark brown friable loam to silt loam, fine crumb to granular structure; 10 to 16 inches thick. The subsurface soil is very dark brown to very dark grayish-brown friable loam to silt loam; weak, very fine subangular blocky structure; 3 to 6 inches thick. The subsoil is very dark grayish-brown to yellowish-brown firm clay loam to sandy clay loam with a few small pebbles; weak, medium subangular blocky structure; neutral; 12 to 20 inches thick.

Soil samples collected in November, 1964, from 15 sites in the check areas at 12- and 24-inch depths were analyzed by the Department of Floriculture at the University of Illinois using the Bray method. From samples taken at the 12-inch depth, the pH readings averaged 6.81; the phosphorus averaged 14.5 and the potassium 189 pounds per acre. At the 24-inch depth, the pH readings averaged 6.96; the phosphorus averaged 7.2 and the potassium 131 pounds per acre. Samples taken in the fall of 1963 at a 6-inch depth averaged 32 pounds of nitrogen per acre. In 1964, the nitrogen analysis at the 12-inch depth ranged from a high of 13 pounds per acre down to a trace.

Three species of trees growing on the experimental area were used in the tests: pin oak (*Quercus palustris* Muench.), white ash (*Fraxinus americana* L.), and honey locust (*Gleditsia triacanthos* L. var. *inermis* Pursh). The trees had been planted in square blocks with 15- to 20-foot spacing distances between trees and 25 feet between blocks. Each block originally contained 100 trees of a single species. The oak and ash had been transplanted to the experimental area in 1956, the locust in 1957. When transplanted, the oaks were 1 to 3 feet tall, the ashes 4 to 6 feet tall, and the locusts 3 to 4 feet tall. Twelve oaks were planted on the area in 1958 to replace oaks that had died. Since several locusts were missing, it was necessary to use trees in two blocks to obtain the desired number for the test.

All blocks had been planted with Kentucky bluegrass, *Poa pratensis* L., and a sod had been maintained with occasional mowing each summer. In the spring of 1963 when the fertilizer tests were started, the oaks averaged 1.64 inches dbh and 10 feet tall, the ashes 2.94 inches dbh and 14 feet tall, and the locusts 1.74 inches dbh and 10 feet tall.

Four methods of application and several fertilizers were used in 16 different combinations (Table 4), each combination designated as a treatment. Each block of trees

FIG. 1.—Part of plot of pin oak trees in the experimental area used for the investigation reported here. This is one of the four test plots located at the Morton Arboretum, Lisle, Illinois. The picture was taken in April, 1965.

was divided into plots, each plot containing five contiguous trees. Each plot received one of the 16 treatments. The treatments were selected at random but in such a way that five trees of each species received one of the 16 treatments. Eighty trees of each species were treated. The remaining trees (14 oak, 12 ash, and 10 locust) received no treatment and served as controls.

Several materials were used as sources of nutrient elements in the fertilizer treatments. Ammonium nitrate (33.5-0-0) and urea (45-0-0) were used as sources of nitrogen. When the dry form of NPK was needed, a commercial 10-10-10 farm fertilizer was used. When a solution of N, P, and K was required, a commercial water-soluble 23-19-17 (*Ra-Pid-Gro*) was used. Source materials for the water-soluble fertilizer were urea, ammonium phosphate, potassium phosphate, and potassium nitrate. When P and K were used in dry form, superphosphate (0-45-0) and muriate of potash (0-0-60) were mixed. For soluble P and K treatments, potassium mono-H phosphate (K_2HPO_4) was used. The minor elements added were contained in *Peters Trace Element Mix*. This mix, prepared from soluble compounds, contained the following minor elements: Mn 9.0%, Fe 6.0%, Cu 3.0%, Zn 3.0%, B 2.0%, Mo 0.5%, and Mg 0.4%.

The type and amount of fertilizer applied to the soil per tree is given in Table 1. The type and amount of fertilizer used per 100 gallons of spray for foliage application is given in Table 2. The amount of nitrogen added to the soil was maintained at 6 pounds of N per 1,000 square feet. Although the per cent of phosphorus and potassium varied slightly in the various fertilizers, an attempt was made to add these elements to the soil at the rate of 6 pounds each of P_2O_5 and K_2O (2.64 pounds of P and 4.98 pounds of K) per 1,000 square feet.

The 1963 soil treatments and the first foliar spray were made on May 14, 15, and 16. The second foliar spray was applied June 20 and the third on July 23. In 1964, each tree received the same treatment it had received in 1963. The soil treatments in 1964 were made on April 22, 23, and 24. The foliar sprays were applied May 20, June 24, and July 24.

A nail was driven into the xylem of each tree approximately 3 feet above the ground, so that it was possible to measure the trunk growth rate at the same tree height on different dates. The original circumference measurements were taken on May 13, 1963. Additional measurements were made October 2, 1963, and October 7, 1964. Because callus growth formed around each nail, the final two measurements on all trees were made one-fourth inch above the nails.

A visual determination of foliage greenness was made once each summer. Each tree was given a rating of 1 to 5,

TABLE 1.—Soil treatments and the rates of application to trees in experimental plots at the Morton Arboretum, Lisle, Illinois, 1963 and 1964.

Plot	Fertilizer	Fertilizer, Grams Per Tree	Elemental Nutrients, Amount Per Tree
1,2,3	Ammonium nitrate (33.5-0-0)	812	272g N
5,6,7	Urea (45-0-0)	605	272g N
15	Superphosphate (0-45-0)	605	120g P
	+ muriate of potash (0-0-60)	454	226g K
16	Potassium mono-H-phosphate	544	97g P; 244 g K
9	Commercial 10-10-10	2,724	272g N; 120g P; 226g K
10	Water soluble 23-19-17	1,185	272g N; 99g P; 167g K
12	Commercial 10-10-10	2,724	272g N; 120g P;
	+ *Peters Trace Element Mix*	85	226g K + minor elements
13	Water soluble 23-19-17	1,185	272g N; 99g P;
	+ *Peters Trace Element Mix*	85	167g K; + minor elements

TABLE 2.—Foliar treatments and amounts used per 100 gallons of spray on trees in experimental plots at the Morton Arboretum, Lisle, Illinois, 1963 and 1964.

Plot	Fertilizer	Fertilizer, Grams Per 100 Gallons*	Elemental Nutrients, Amount Per 100 Gallons
4	Ammonium nitrate (33.5-0-0)	1,557	522g N
8	Urea (45-0-0)	1,158	522g N
11	Water soluble 23-19-17	2,270	522g N; 190g P; 320g K
14	Water soluble 23-19-17	2,270	522g N; 190g P;
	+ *Peters Trace Element Mix*	340	320g K + minor elements

* Oak and locust received approximately 1.5 gallons of spray per tree and ash approximately 2 gallons of spray per tree for each application.

based on the following scale: 1, yellow green; 2, light green; 3, green; 4, moderately dark green; and 5, dark green. The 1963 color ratings were made on September 9 and the 1964 ratings on July 24. Each recorded rating was the average of the ratings made by two observers.

Precipitation data (Table 3) were obtained from the nearest weather station, at Wheaton College, about 3 miles from the experimental area. In both 1963 and 1964, rainfall was below average. This shortage was evident during the fall and winter. Spring and summer rainfall was near or above normal.

Four currently used methods of fertilizing established trees were included in the tests: surface broadcasting, placement of dry fertilizer in holes made in the soil, injection of fertilizer solutions into the soil, and foliar feeding.

TABLE 3.—Precipitation data from the Wheaton College weather station, Wheaton, Illinois.

Year	Jan. Feb. March	April May June	July Aug. Sept.	Oct. Nov. Dec.	Total
1963	4.05	10.44	10.30	3.61	28.40
1964	4.35	9.90	12.42	3.85	30.52
*Normal**	*6.03*	*11.11*	*9.68*	*6.62*	*33.44*

* Normal is an average of approximately 80 years of data taken from records of weather stations located in the Northeast Climatological Division of Illinois.

FIG. 2.—Electric drill being used to make holes in which dry fertilizer is placed in the soil around trees. The electric-drill method of making holes is more rapid than the punch-bar method, but it requires a heavy-duty drill and a source of electricity. It is especially useful when the soil is dry.

Surface Broadcasting of Fertilizers

Since the penetration of phosphorus and potassium into the soil is limited, only nitrogen was tested by surface broadcasting. One of two readily available nitrogen sources, ammonium nitrate and urea, supplied in the pellet form, was broadcast on the soil surface around each tree. The fertilizer required for each tree was weighed and broadcast by hand as uniformly as possible within a circular area having a radius of 5½ feet. The area treated was approximately 100 square feet. Most of the root system of each of the treated trees was assumed to be included in this area. Natural rainfall was depended upon to carry the ammonium nitrate and urea into the soil.

Placement of Dry Fertilizers in Holes

Five fertilizers were evaluated by being applied, in dry form, in holes made in the soil. The fertilizers used were ammonium nitrate, urea, PK, NPK, and NPK plus minor

FIG. 3.—Punch-bar being used to make holes in which dry fertilizer is placed in the soil around trees.

elements. In 1963, the soil was sufficiently dry at the time of treatment to require that the holes be made with a drill or a soil profile tube. For the large amounts of NPK or NPK plus minor elements needed, holes 2 inches in diameter were made with an electric drill (Fig. 2). For the smaller amounts of N or PK fertilizers required, holes were made with a soil profile tube three-fourths inch in diameter. In 1964, the soil was wet at the time of treatment and the punch-bar method of making holes was used (Fig. 3 and 6).

The amount of fertilizer for each tree was weighed and distributed equally in 18 holes around each tree (Fig. 4);

each hole was 12 to 15 inches deep. Six of the holes were made in a circle having a radius of approximately $2\frac{1}{2}$ feet. The remaining 12 holes were distributed in a circle having a radius of $4\frac{1}{2}$ feet, sufficient to include most of the root system of the treated tree. After the fertilizers had been applied, no attempt was made to fill the holes, and no supplemental watering was done.

Injection of Liquid Fertilizers

The five kinds of fertilizers applied in holes were applied also by the soil injection method. Solutions of the five fertilizers were injected 18 to 24 inches deep with a soil needle (Fig. 5 and 6) and a hydraulic sprayer at 150 pounds pressure. The volume of fertilizer used at each injection point was carefully regulated by opening the soil needle valve for a predetermined number of seconds. Fifteen gallons of a fertilizer solution were used per tree. The 15 gallons of liquid fertilizer were evenly divided among 14 injection points about each tree. Four injections were made on four sides approximately $2\frac{1}{2}$ feet from the tree trunk, and the remaining 10 injections were made in a

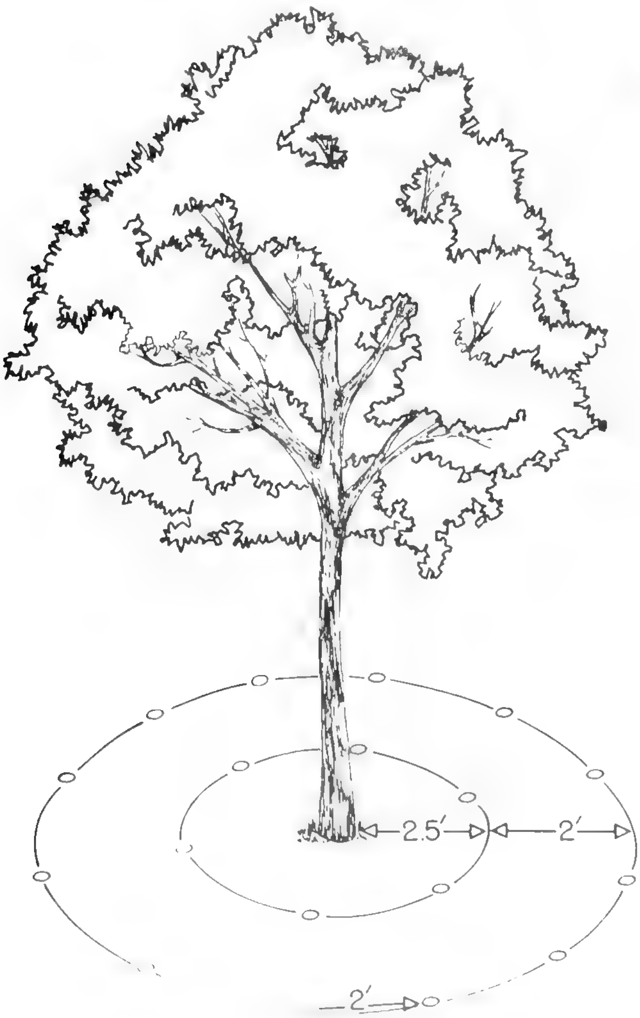

FIG. 4. Diagram illustrating the placement of holes around an experimental tree fertilized by the dry fertilizer-in-holes method.

FIG. 5.—Hydraulic injection of liquid fertilizer at 150 pounds pressure through a soil needle.

FIG. 6. Punch-bar (left) and soil needle designed and used by the authors of this publication. The punch-bar is made of a hardened steel axle on which are welded a foot rest and a handle. The soil needle is like types available commercially.

FIG. 7.—Foliage application of a liquid fertilizer. A hydraulic sprayer is used in this operation. The solution was applied until it began to drip from the foliage.

circle approximately 4½ feet from the trunk. The 225 gallons of liquid fertilizer required for each treatment (three tree species, five trees each) were prepared in a 300-gallon hydraulic sprayer tank having an agitator.

Foliar Applications of Fertilizers

In a series of foliar applications, ammonium nitrate was compared with urea, and NPK alone was compared with NPK plus trace elements. *Ra-Pid-Gro* was used for the NPK source, and *Ra-Pid-Gro* with additional minor elements added was used as the NPK plus trace elements. All of these materials are water soluble. Because of possible foliage burn, the amount of material applied as a spray was necessarily less than that used for the soil applications. *Ra-Pid-Gro* was used at the rate of 5 pounds per 100 gallons of water currently recommended for foliar application. For the NPK plus minor elements, three-fourths pound (340 grams) of *Peters Trace Element Mix* per 100 gallons of spray was added to *Ra-Pid-Gro*. The concentration of N used was the same in all of the foliar treatments. The spray solution was applied to the foliage with a hydraulic sprayer (Fig. 7) until the solution began to drip from the foliage. No effort was made to prevent runoff to the soil. Three foliar sprays, the first one the third week of May, were applied at approximately 1-month intervals each year of the experiment. All of the foliar sprays were applied between 8 AM and 12 noon on days having little or no wind.

EXPERIMENTAL RESULTS OF TREE FERTILIZATION

The increases in circumference of the experimental shade trees given the various fertilizer treatments tested during 1963 and 1964 are shown in Table 4. Each circumference figure shown for the treated trees is the average obtained from five contiguous trees in a plot. The circumference figure for each control group is an average for untreated trees of the species represented: 14 pin oaks, 12 white ashes, 10 honey locusts. The totals for the 2 years were analyzed statistically, and significant differences between treatments at the 1% and 5% levels were noted.

TABLE 4.—Average increases in growth of three deciduous hardwoods following various fertilization treatments at Lisle, Illinois, 1963 and 1964. Each average for treated trees represents five contiguous trees in a plot. The averages for untreated (control) trees are based on 14 pin oaks, 12 white ashes, and 10 honey locusts.

			Circumference Increase (0.001 Foot)								
		Application	Pin Oak			White Ash			Honey Locust		
Fertilizer	Plot	Method	1963	1964	Total	1963	1964	Total	1963	1964	Total
NH_4NO_3	1	Surface	127	167	294**	132	129	261**	139	166	305**
	2	Holes	135	173	308**	94	118	212	80	116	196*
	3	Solution	145	172	317**	105	107	212	123	176	299**
	4	Foliar	92	135	227	105	85	190	63	56	119
Urea	5	Surface	129	165	294**	95	108	203	128	148	276**
	6	Holes	131	176	307**	105	110	215	65	97	162
	7	Solution	120	152	272*	130	143	273**	111	137	248**
	8	Foliar	94	116	210	92	92	184	54	50	104
NPK	9	Holes	109	161	270*	108	109	217	73	88	161
	10	Solution	166	203	369**	127	134	261**	85	102	187*
	11	Foliar	82	122	204	80	70	150	49	49	98
NPK + trace elements	12	Holes	107	200	307**	97	118	215	76	100	176
	13	Solution	127	166	293**	109	121	230*	106	118	224**
	14	Foliar	69	119	188	97	103	200	56	52	108
PK	15	Holes	91	117	208	82	83	165	48	50	98
	16	Solution	90	112	202	71	64	135	56	53	109
Controls	17	No treatment	84	116	200	88	78	166	69	67	136
Least significant difference at the 5% level					55.2			63.9			49.3
Least significant difference at the 1% level					73.5			85.0			65.6

* Significant at the 5% level.
** Significant at the 1% level.

A summary of the results from four different methods of applying nitrogen-containing fertilizers to the experimental shade trees is given in Table 5. These data were obtained by averaging data from the nitrogen-containing treatments listed in Table 4. Data from treatments 15 and 16, in which only P and K were used, are not included in Table 5. The amount of N applied per tree was the same for each method of application except the foliar spray.

TABLE 5.—Average increases in growth of three deciduous hardwoods during a 2-year period of nitrogen fertilization treatments at Lisle, Illinois, 1963 and 1964.

Method of Application	Plot	Circumference Increase (0.001 Foot) Pin Oak	White Ash	Honey Locust
Surface application	1,5	294	232	291
Dry in holes	2,6,9,12	298	215	174
Solution injection	3,7,10,13	313	244	240
Foliar spray	4,8,11,14	207	181	107
No treatment	17	200	166	136

TABLE 6.—Average increases in growth of three deciduous hardwoods during a 2-year period of soil fertilization treatments at Lisle, Illinois, 1963 and 1964. (Trees given foliar applications are not included.)

Fertilizer	Plot	Circumference Increase (0.001 Foot) Pin Oak	White Ash	Honey Locust
NH_4NO_3	1,2,3	306	228	267
Urea	5,6,7	291	230	229
NPK	9,10	320	239	174
NPK + trace elements	12,13	300	223	200
PK	15,16	205	150	104
No treatment	17	200	166	136

Trees given the foliar spray did not make substantially greater growth than the unfertilized trees (Table 5). Growth differences between these two groups of trees were no greater than would be expected from normal biological variation.

The three methods of soil application appeared to be about equally effective on pin oak. On white ash, the solution injection method produced a noticeably greater response than the hole method of soil application. On honey locust, the surface application produced the greatest response. Of the three methods of soil application, surface application produced the greatest amount of total growth on trees of the three species combined. The precipitation that occurred from April through September in both 1963 and 1964 (Table 3) was adequate to carry the surface-applied fertilizer into the soil.

The response of the experimental shade trees to five fertilizers applied to the soil is summarized in Table 6. The data were obtained by averaging data from the soil treatments included in Table 4. Growth of only those trees receiving nitrogen treatments was significantly better than growth of the untreated trees. The application of phosphorus and potassium to the soil did not bring about a significant growth response; nor did a combination of phosphorus, potassium, and nitrogen produce a response that was significantly greater than that produced by nitrogen alone. The addition of minor elements to NPK produced no significant growth response. Ammonium nitrate and urea appeared to be about equally effective as nitrogen sources. The addition of nitrogen to the soil resulted in

TABLE 7.—Color ratings (1 to 5)† of three deciduous hardwoods following various fertilization treatments at Lisle, Illinois, 1963 and 1964. Each color rating for treated trees represents the average for five contiguous trees in a plot.

Fertilizer	Plot	Method of Application	Pin Oak 1963	Pin Oak 1964	White Ash 1963	White Ash 1964	Honey Locust 1963	Honey Locust 1964
NH_4NO_3	1	Surface	4.6**	4.7**	4.3*	4.9**	4.3**	4.6**
	2	Holes	3.8	4.7**	3.8	4.3*	3.8	3.9*
	3	Solution	4.0*	4.4**	3.6	4.0	4.0*	5.0**
	4	Foliar	2.8	3.4	3.5	3.1	3.5	3.3
Urea	5	Surface	4.0*	3.4	3.5	3.2	4.8**	5.0**
	6	Holes	4.0*	3.4	3.4	3.4	4.0*	5.0**
	7	Solution	3.2	3.5	3.7	4.1	4.0*	4.8**
	8	Foliar	2.8	4.8**	3.4	4.1	3.0	3.5
NPK	9	Holes	3.8	4.5**	3.8	4.1	3.6	4.0**
	10	Solution	4.8*	5.0**	3.9	4.2*	3.9*	5.0**
	11	Foliar	3.0	3.5	3.0	3.2	3.4	3.4
NPK + trace elements	12	Holes	4.2**	5.0**	3.5	4.0	4.2**	4.3**
	13	Solution	4.8**	4.7**	3.7	4.3*	4.2**	4.3**
	14	Foliar	3.2	3.6	3.6	3.8	3.3	3.2
PK	15	Holes	3.0	4.6**	3.3	3.7	3.3	3.7
	16	Solution	3.2	3.6	3.0	3.7	3.0	3.3
Controls	17	No treatment	3.1	3.5	3.5	3.2	3.3	3.2
Least significant difference at the 5% level			0.73	0.58	0.78	0.91	0.56	0.54
Least significant difference at the 1% level			0.97	0.77	1.04	1.21	0.75	0.72

†Color rating: 1, yellow green; 2, light green; 3, green; 4, moderately dark green; 5, dark green.
* Significant at the 5% level
** Significant at the 1% level.

TABLE 8.—Color ratings (1 to 5)† of three deciduous hardwoods during a 2-year period of fertilization treatments at Lisle, Illinois. Each color rating for treated trees represents the average for five contiguous trees in a plot.

Method of Application	Plot	Pin Oak		White Ash		Honey Locust	
		1963	1964	1963	1964	1963	1964
Surface	1,5	4.3	4.1	3.9	4.1	4.6	4.8
Holes	2,6,9,12	4.0	4.4	3.6	4.0	3.9	4.3
Solution	3,7,10,13	4.2	4.4	3.7	4.2	4.0	4.8
Foliar	4,8,11,14	3.0	3.8	3.4	3.6	3.3	3.4
No treatment	17	3.1	3.5	3.5	3.2	3.3	3.2

† Color rating: 1, yellow green; 2, light green; 3, green; 4, moderately dark green; 5 dark green.

TABLE 9.—Color ratings (1 to 5)† of three deciduous hardwoods during a 2-year period of fertilization treatments at Lisle, Illinois. Each color rating for treated trees represents the average for five contiguous trees in a plot.

Fertilizer	Plot	Pin Oak		White Ash		Honey Locust	
		1963	1964	1963	1964	1963	1964
NH_4NO_3	1,2,3	4.1	4.6	3.9	4.4	4.0	4.5
Urea	5,6,7	3.7	3.4	3.5	3.6	4.3	4.9
NPK	9,10	4.3	4.8	3.9	4.2	3.8	4.5
NPK + trace elements	12,13	4.5	4.9	3.6	4.2	4.2	4.3
PK	15,16	3.1	4.1	3.2	3.7	3.2	3.5
No treatment	17	3.1	3.5	3.5	3.2	3.3	3.2

† Color rating: 1, yellow green; 2, light green; 3, green; 4, moderately dark green; 5 dark green.

growth that, measured by circumference increase, was considerably greater than growth of the controls: 52% greater in the pin oak, 39% greater in the white ash, and 73% greater in the honey locust.

The color data for the fertilizer treatments of the three tree species in the 1963 and 1964 tests are shown in Table 7. These data were analyzed statistically. The color response to the various methods of treatment is presented in Table 8. Nitrogen fertilizers applied to the soil surface, in holes made in the soil, or as solutions injected into the soil, produced a foliage color that was significantly darker than foliage color of the trees receiving no treatment. During the 2-year test, the solution injection and surface broadcast methods appeared slightly better than the soil-hole method.

The foliage color of the trees receiving foliar fertilization was not significantly better than the foliage color of the untreated trees. In the first year of the experiment, no difference in color of foliage could be detected between the trees receiving foliar treatments and the untreated trees. In the second year, the foliage of all three tree species receiving foliar fertilization appeared slightly darker in color than foliage of the untreated controls. However, the response to foliar fertilization was not nearly as marked as the response obtained from any one of the three soil fertilization methods.

A comparison of the color responses to the various fertilizers tested is presented in Table 9. Only those trees receiving fertilizer treatments containing nitrogen had leaves that were significantly darker green in color than leaves of the untreated controls. There was little or no color response to phosphorus and potassium applied to the soil. The addition of phosphorus and potassium to nitrogen sources did not produce a color response that was greater than that produced by nitrogen alone. The addition of minor elements to NPK produced no measurable color response. Ammonium nitrate as a source of nitrogen appeared to give a darker green color to leaves of oak and ash than did urea; on locust, urea appeared more effective than ammonium nitrate in producing the darker color.

TOXICITY OF FERTILIZERS TO BLUEGRASS

Because some of our experiments showed that surface applications of nitrogen fertilizers constituted a practical and economical method for fertilizing established shade trees, we conducted additional experiments to determine the rates at which these applications could be made without injuring the grass that is commonly found under and around such trees.

Wyman (1936) reported a 2-year test on the application of ammonium sulfate (20-0-0) to a lawn at rates as high as 20 pounds of N per 1,000 square feet. He found that on dormant Kentucky bluegrass, when precipitation was ample, no injury resulted from ammonium sulfate applied at rates of 10 pounds of N per 1,000 square feet and no serious injury at rates as high as 16 pounds. After the grass had started to grow, 4 pounds of N per 1,000 square feet were applied without injury to grass; 10 pounds per 1,000 square feet caused considerable burning but left some grass green.

In tests at the Morton Arboretum, we observed no injury to the Kentucky bluegrass, *Poa pratensis* L., growing

beneath the oak, ash, or locust trees treated by surface application with urea or ammonium nitrate at the rate of 6 pounds of N per 1,000 square feet. Also, we observed no injury to grass when the fertilizer was applied dry in holes or injected into the soil in solution. Since such variables as time of application, rate of application, and the presence or absence of moisture droplets on the grass blades were not investigated in the Morton Arboretum tests, we included these variables in a series of fertilizer toxicity tests on a lawn near Urbana, Illinois, in the spring and summer of 1964.

The lawn of a farm residence 1 mile south of Urbana was used in this study. The lawn was predominantly Kentucky bluegrass. It had no history of previous fertilization. The grass was regularly cut throughout the test to a height of approximately 3 inches. Rain provided the only source of water except in one of the tests in which the grass was sprinkled to simulate a heavy dew. A lawn fertilizer spreader, 20 inches wide and typical of the push type commonly used by homeowners (Fig. 8), was calibrated to spread 3 pounds of N per 1,000 square feet of soil surface for each of the five fertilizers used in this test. The five fertilizers applied were ureaform, urea, 10-10-10, ammonium nitrate, and ammonium sulfate.

Each fertilizer was applied at rates of 3, 6, 9, and 12 pounds of N per 1,000 square feet on April 15, May 15, and July 30 in bands 20 inches wide and 20 feet long. The 6-pound rate required two applications at the 3-pound rate; the 9-pound rate required three applications; and the 12-pound rate required four applications. An additional test was made on May 15 and July 30 to compare the effect of applying fertilizers to wet grass. For this test, a strip of lawn 10 feet long was sprinkled with water immediately prior to applying the 20-inch-wide band of fertilizer.

FIG. 8.—Surface application of dry fertilizer. A common lawn fertilizer spreader may be used in applying fertilizer to either grass or trees.

Observations were made 4 and 7 days after each application, and the phytotoxicity of each application was rated on a scale of 0 through 7 (Table 10). No injury was recorded for the April 15 applications. Some injury resulted from several of the May 15 and July 30 applications. Ureaform caused no observable injury at any time, or in any amount used, on either dry or wet grass. Urea used

TABLE 10.—Phytotoxicity ratings (1 to 7)† of five fertilizers applied to Kentucky bluegrass at Urbana, Illinois, 1964.

Fertilizer	Per Cent N	Pounds of N Per 1,000 Square Feet	Applied to Dry Grass April 15	Applied to Dry Grass May 15	Applied to Dry Grass July 30	Applied to Wet Grass May 15	Applied to Wet Grass July 30
Ureaform	38.0	12	0	0	0	0	0
		9	0	0	0	0	0
		6	0	0	0	0	0
		3	0	0	0	0	0
Urea	45.0	12	0	2	0	4	0
		9	0	1	0	3	0
		6	0	0	0	1	0
		3	0	0	0	0	0
10-10-10	10.0	12	0	2	0	7	4
		9	0	0	0	6	2
		6	0	0	0	5	2
		3	0	0	0	4	0
NH_4NO_3	33.5	12	0	3	6	7	6
		9	0	2	6	5	6
		6	0	0	4	4	4
		3	0	0	2	2	2
$(NH_4)_2SO_4$	21.0	12	0	2	0	6	2
		9	0	2	0	6	2
		6	0	0	0	4	2
		3	0	0	0	0	0

† Phytotoxicity ratings based on injury to Kentucky bluegrass: 0, none; 1, very slight; 2, slight; 3, slight to moderate; 4, moderate; 5, moderate to severe; 6, severe; 7, very severe.

at the rate of 6 pounds of N per 1,000 square feet caused no injury when applied on dry grass and only very slight injury when applied on wet grass. The 10-10-10 formulation caused no injury when applied on dry grass at rates of 9 pounds or less of N per 1,000 square feet; at even 3 pounds of N on wet grass it caused some injury. Both ammonium nitrate and ammonium sulfate were safely applied in the spring at 6 pounds of N per 1,000 square feet. Ammonium nitrate applied in July, when the soil was dry, caused injury at all application rates. However, all the fertilizer burn was temporary. No burn from any treatment was evident on October 1.

The probable explanation for lack of injury from the first (April 15) fertilizer applications may be found in precipitation data for the area. Rain fell on 5 of the 7 days following the April 15 applications; precipitation recorded by the Urbana weather station for these days totaled 5.92 inches. Rain fell on 3 of the 7 days following the May 15 application; precipitation totaled 0.10 inch. No precipitation occurred during the 7 days following the July 31 application. Rainfall following heavy applications of fertilizer may reduce the phytotoxic effect of the fertilizer. Under normal lawn conditions, the fertilized area should be heavily watered with a lawn sprinkler.

Under the conditions of this lawn fertilization test, it appeared that most nitrogen-containing fertilizers can be safely broadcast on dry Kentucky bluegrass at the rate of 6 pounds of N per 1,000 square feet. Moderate burn of grass blades may occur when fertilizer is applied at this rate on wet grass. Higher rates of application are possible if fertilization is followed within a few hours by precipitation sufficient to wash the fertilizer off the leaf blades. Supplemental watering would undoubtedly lessen the amount of injury that might occur following heavy applications of N. Even in plots receiving the heaviest applications of fertilizers, all signs of burning disappeared a month after the fertilizer had been applied.

DISCUSSION

Recommendations for fertilization of shade trees should specify time of fertilization, type and amount of fertilizer to be used, and method or methods of application. Time of fertilization and amount of fertilizer are variables not investigated in our tree study reported here. All of our fertilizer treatments were applied in the spring. All of our experimental trees received fertilizer at the rate of 6 pounds of N, P_2O_5, or K_20 per 1,000 square feet of area. This rate was selected since it is approximately equivalent to the amount of fertilizer commonly recommended for established shade trees and is a rate known to be nontoxic to grass and trees when the fertilizer is applied dry in holes.

Formulas that have been used for determining the amount of fertilizer to be applied are varied, and some of them are difficult for the average arborist to follow. One of these formulas employs the sum of the following: the height of the tree in feet, the branch spread in feet, and the trunk circumference in inches 1 foot above the soil line. The total of these figures is the number of pounds of 10-8-6 fertilizer to apply in holes. The most common formula now used is based on the diameter of the tree trunk at breast height. Trees of 6 inches dbh or larger receive one-half pound of nitrogen per inch of trunk diameter; smaller trees receive one-fourth pound of nitrogen per inch of trunk diameter. Another formula specifies 3 pounds of a balanced fertilizer per inch of trunk diameter.

Wikle (1963), in a discussion of shade tree fertilization, emphasized the large differences between various application rates that are based on trunk diameter. He recommended that the rates be based on the area of soil to be treated, not on trunk diameter. We agree with his recommendation. The basic reason for application of fertilizer is to supplement the nutrients naturally available in the soil occupied by the tree roots, which, for most species, extend at least as far as branch spread. Such a recommendation greatly simplifies the problem of determining the amount of fertilizer to be applied.

The answer to the question, "Should I or shouldn't I fertilize this tree?" depends on the answers to a number of other questions. What is the soil type? Has the character of the soil type been changed by previous management practices? Will the use of nitrogen in a fertilizer give a measurable growth response? Will the addition of other soil elements to the fertilizer give additional growth response? Is the tree of such an age and species that it will respond to the use of fertilizer? Will increased soil fertility resulting from use of fertilizer prevent or at least retard tree decline or dieback from certain physiological or pathological diseases?

Much research must be done before these questions can have adequate answers. To some of the questions, research already reported has given only partial answers, and, to other questions, conflicting answers.

Our use of nitrogen-containing fertilizers on pin oak, white ash, and honey locust in northern Illinois resulted in an increase in tree circumference that was 39% to 73% greater than the increase for untreated trees. To what extent certain other tree species will respond to fertilizers containing nitrogen or other nutrient elements can be determined only through additional controlled experimentation. In our northern Illinois tests, significant growth response was obtained from nitrogen and from no other nutrient element. In Ohio and New York tests, growth response was reported from use of nitrogen and additional growth response when phosphorus was added to nitrogen.

The method used in applying fertilizers is especially important because it determines to a great extent the cost of the operation and the ease with which it is accomplished. The drilled hole method and the solution injection method are relatively expensive, for they require considerable time and expensive equipment. The punch-bar method requires a great amount of labor and time. The surface broadcast method is fast and requires only that equipment already owned by most gardeners or arborists. In our tests, the tree response to nitrogen applied to the soil surface was comparable to the response to nitrogen placed in the soil.

Foliar applications of nutrients for tree fertilization appear to have only limited usefulness. In our tests, trees given the foliar spray did not make substantially greater growth than unfertilized trees, and the color of the foliage of the treated trees was not significantly better than that of unfertilized trees.

Several considerations favor shade tree fertilization. The cost of the fertilization is negligible in comparison with the high aesthetic value homeowners place upon their trees. Lawns are not injured by the fertilization; in fact, the growth of grass is stimulated by the use of fertilizers applied at rates required to obtain good growth in trees.

Trees of some species that have few desirable qualities other than that they grow rapidly are now planted by some homeowners and municipalities because quick replacement of shade is demanded. With additional information on shade tree fertilization, it should be possible to make greater use of some tree species that heretofore have not been used extensively because they are considered slow-growing. Some of these species may be used as replacements of American elms killed by the Dutch elm disease. Slow-growing tree species having otherwise desirable characteristics may be planted and, through fertilization, stimulated to grow faster.

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ABSTRACT

Fertilization experiments were carried out in 1963 and 1964 on pin oak, white ash, and honey locust in block plantings established for 7 years at the Morton Arboretum, Lisle, Illinois. Sixteen fertilizer treatments (each of the treatments a different combination of fertilizer and method of application) were used on each tree species. Four methods of application were used: surface broadcasting, placement of dry fertilizers in holes made in the soil, injection of liquid fertilizers into the soil, and spraying of foliage. The following nutrient elements or combinations of elements were used: N, PK, NPK, and NPK plus minor or trace elements.

The addition of nitrogen to the soil at the rate of 6 pounds per 1,000 square feet resulted in tree circumference increases greater than the increases in untreated controls: 39% greater in white ash, 52% greater in pin oak, and 73% greater in honey locust. The application of phosphorus and potassium to the soil did not bring about a significant growth response; nor did a combination of phosphorus, potassium, and nitrogen produce a response that was significantly greater than that produced by nitrogen alone. The addition of minor elements to NPK produced no significant growth response.

The three methods of soil application appeared to be about equally effective, with minor variations among the tree species. Surface application produced the greatest amount of total growth on trees of the three species considered together. Foliar sprays did not produce a substantially greater growth than the growth of unfertilized controls.

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